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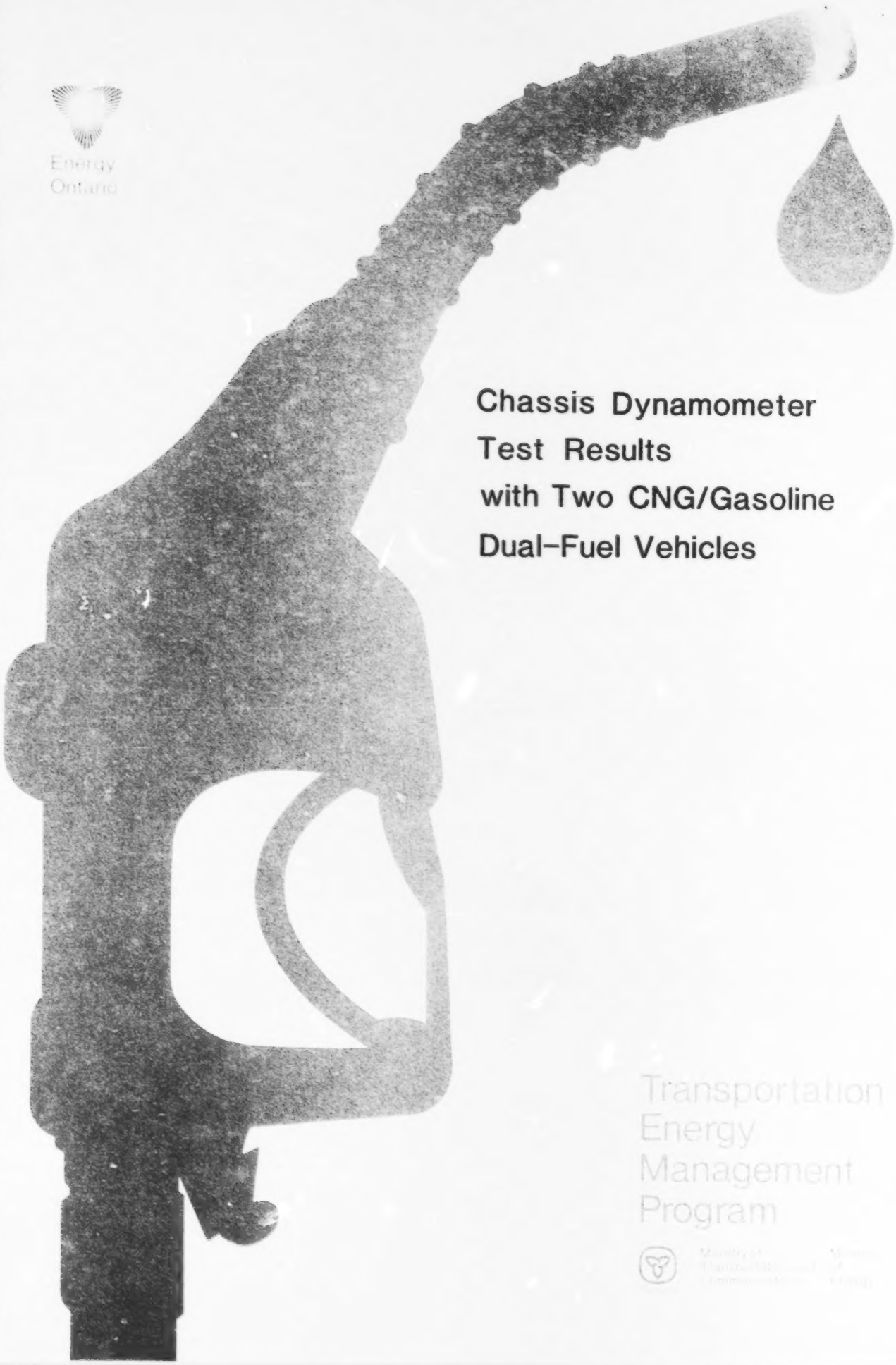

Chassis Dynamometer Test Results with Two CNG/Gasoline Dual-Fuel Vehicles

Transportation Energy Management Program

Ministry of Transportation and Communications

Ministry of Energy

AF-82-02

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Fuel Consumption, Exhaust Emissions, and Performance

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Published by:
The Transportation Energy Management Program (TEMP)
Ontario Ministry of Transportation and Communications
Hon. James W. Snow, Minister
H.F. Gilbert, Deputy Minister

Ontario Ministry of Energy
Hon. Robert Welch, Minister
Malcolm Rowan, Deputy Minister

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ACKNOWLEDGEMENTS

The author would like to express his gratitude to Cecil Simmons, Norm Perfect and their staff for their valuable assistance in preparing the vehicles and in carrying out the fuel consumption, performance and emissions tests.

All members of the Automotive Energy Group have contributed to this report with their comments and suggestions. I am especially indebted to Ovi Colavincenzo for his constant encouragement and support.

EXECUTIVE SUMMARY

The demonstration of compressed natural gas (CNG) as a transportation fuel is being carried out by Consumers' Gas with the assistance of the Ontario Government. A fleet of 22 CNG/gasoline dual-fuel vehicles and a CNG fueling station are in operation. Their performance is being carefully monitored to produce the data needed for optimization of future applications.

In an effort to assess the effectiveness of the CNG conversion equipment and technique used by Consumers' Gas, two of their dual-fuel utility vans were tested at the MTC chassis dynamometer facility. The fuel consumption, exhaust emissions, and performance of these vehicles were measured with gasoline and natural gas on a set of well-defined driving cycles and under controlled environmental conditions.

The test results indicate that vehicles running on natural gas may achieve energy utilization efficiencies comparable to and higher than those achieved while running on gasoline. However, efficiency improvements are not guaranteed with every application. Successful application appears to require optimization of the engine/conversion kit combination. Higher energy efficiencies are accompanied by a significant reduction in carbon monoxide emissions and peak power rating. No major effects were observed on tne emission of hydrocarbons and nitrogen oxides.

This test program will be complemented by a systematic engine/conversion kit optimization and by testing on the road, and chassis and engine dynamometers.

1/ INTRODUCTION

The utilization of compressed natural gas (CNG) as a transportation fuel is being pioneered in Ontario by Consumers' Gas who are now operating a CNG fueling station and a fleet of 22 CNG/gasoline dual-fuel vehicles. In the near future, similar small-scale fleet applications may be initiated in Ontario. These are crucial demonstrations whose success will influence the future of natural gas as a transportation fuel. Consequently, the Ministry of Transportation and Communications has considered it necessary to follow the progress of these demonstrations and to assist industry in its efforts to surmount initial technical difficulties.

In contribution to the above goals, two of the Consumer's Gas utility vans converted to run as dual-fuel (CNG/gasoline) vehicles were subjected to a series of chassis dynamometer tests at the MTC facilities by MTC staff. The fuel consumption, exhaust emissions, and performance of the two vehicles were measured using gasoline and natural gas on a set of well-defined driving cycles and under controlled environmental conditions.

One of the objectives of the test program was to assess the effectiveness of the CNG conversion equipment and conversion technique used by Consumers' Gas. The results summarized in this report may contribute to this objective; however, for a definitive assessment, further experimentation with this and similar equipment is necessary.

2/ EXPERIMENTAL PROCEDURE

Vehicle fuel consumption, exhaust emissions, and performance were measured in the MTC test laboratory using a Clayton Model ECE-50 chassis dynamometer equipped with an automatic road load power control system and a direct-drive variable inertia weight system (1000 to 8750 lb range, 125 lb increments), a constant volume sampling system, emissions analyzers, and a computerized data reduction system. Details of the test laboratory, the equipment therein, and the test procedure may be found in the MTC report LAB-81-01.

Fuel consumption and exhaust emissions were measured over the Transport Canada city and highway test cycles described in Figure 1. The city cycle consists of three phases. The first phase (cold-transient phase) involves a cold-start and 505 s of driving. The second phase (stabilized phase) is driven immediately after the first phase, and its duration is 866 s. The engine is then turned off for 10 min, after which the first 505 s of the test are repeated. This last segment of driving constitutes the hot-transient phase. Vehicle exhaust emissions are measured individually for each phase. To assure repeatability and representativeness, the city cycle is preceded by a preconditioning step which includes driving the vehicle on the dynamometer over a complete test cycle and then storing it for 12 to 36 h under controlled conditions (20 to 30°C).

For the highway fuel consumption and emissions testing, the vehicle is driven twice over the 765 s driving cycle shown in Figure 1. The first run constitutes preconditioning -- no exhaust gas sampling is required here. This run is followed by a 15 s idle period and the second run during which the exhaust gases are sampled and analyzed.

In all fuel consumption tests (i.e., city, highway, cruise and idle tests), the concentrations of hydrocarbons, carbon monoxide, carbon dioxide and oxides of nitrogen are measured accurately. These measurements are then used in a mass balance (carbon balance) to determine vehicle fuel consumption under standard ambient conditions.

The dynamometer parameters applicable for the city and highway tests are summarized in Table 1. The inertia weight and actual road load values

are obtained from the U.S. Environmental Protection Agency Emissions Test Laboratories. The test cell temperature, pressure and dew point temperature recorded in Table 2 are used in the prediction of exhaust emissions and fuel consumption under standard ambient conditions.

Vehicle performance was estimated by measuring the time period necessary to accelerate from zero to 96.6 km/h (60 mph) on the dynamometer. In addition, the power delivered at the wheels by the engine at 80.0 km/h and in wide-open-throttle operation was estimated roughly by conducting coast-down and acceleration tests over a speed range of 77.3 to 83.7 km/h (48 to 52 mph) on the dynamometer.

The two test vehicles employed in this test program were Consumers' Gas utility vans with specifications listed in Table 2. They were tested both on gasoline and natural gas. Results obtained with gasoline served to estimate the baseline characteristics of the vehicles calibrated according to manufacturers' specifications by Consumers' Gas. The major calibration settings affecting fuel consumption were checked at MTC (Table 3); however, no adjustments were made to any of the settings. The calibration settings selected by Consumers' Gas for the dual-fuel vehicle were also checked and recorded in Table 3.

It should be emphasized that in the baseline tests the vehicles were set to the manufacturers' specifications for gasoline. In the CNG tests, the vehicles were set to specifications which Consumers' Gas considered appropriate for dual-fuel operation. Specifically, the spark-timing in dual-fuel operation is a compromise for operation with natural gas and gasoline.

The energy content of the gasoline used in testing was estimated by measuring the density of the fuel. A density reading of 0.738 kg/L suggested a lower heating value of 32.4 MJ/L (18 900 Btu/lb or 140 000 Btu/gal). The lower heating value of the natural gas at standard temperature and pressure conditions was estimated as 33.6 MJ/m^3 (903.1 Btu/ft^3). This estimate is based on the fuel composition analysis supplied by Consumers' Gas, viz., 95.5% CH_4, 2.0% C_2H_6, 0.1% C_3H_8, 0.01% C_4H_{10}, 1.8% N_2, 0.34% CO_2.

The above data result in an energy equivalence of 0.96 m^3 NG/1 L gasoline or 154 ft^3 NG/1 imp. gal. of gasoline.

3/ EXPERIMENTAL RESULTS

The fuel consumption, exhaust emissions and performance results obtained with gasoline are summarized in Table 4 and those obtained with CNG in Table 5. The fuel consumption data were also reduced to energy consumption in order to provide a common basis of comparison between the two fuels. These results are presented in Table 6 and Figures 2 and 3. Note that, in computing energy consumption, the lower heating values of the two fuels were used.

All figures in Tables 4, 5, and 6 represent arithmetic averages of two results. In the fuel consumption data, largely based on CO_2 concentration data, test-to-test variability was less than 3%. In the exhaust emissions data, the variability was much higher; especially, in the cold-start portion of city tests.

The baseline tests carried out with gasoline (Table 4) indicate that the fuel consumption of the first (GMC) and second (Ford) van are comparable. The exhaust emissions of the second van are higher; especially, those of NO_x and CO. The performance of this van is significantly lower, too.

NO_x emission levels as high as those observed here suggest malfunctioning of the vehicle exhaust gas re-circulation (EGR) system. A totally closed EGR valve will increase the peak combustion temperature and, as a result, NO_x emissions. Observation of higher CO concentrations in the presence of higher combustion temperatures may be the result of poor carburetion or ignition. An "Orsat Analysis" was performed to deduce the average combustion gas mixture composition of the two vehicles under cruise conditions at 48.3 and 96.6 km/h. The results indicate that, under these conditions, both vehicles are burning lean mixtures. The measured air-to-fuel rations on a mass basis were in the range of 17 to 19. It should be noted, however, that this analysis provides data on the overall gas composition under steady-state conditions only. It does not provide information on the conditions in individual engine cylinders and on the system behaviour under transient conditions.

The CNG tests indicate that conversion to CNG produced, in general, reduced energy consumption with the first vehicle (GMC van) and increased

fuel consumption with the second (Ford van). Specifically, in the cruise tests we observe 9 to 10% improvement in energy utilization with the first vehicle and 13 to 14% deterioration with the second (Table 6). In the idle mode, energy consumption increased with both converted vehicles.

In order to compare natural gas and gasoline fuel consumption with the theoretical fuel consumption, the experimental data for each vehicle obtained in urban, highway and cruise driving modes were cross-plotted. In the resulting figure, Figure 4, the fuel equivalence takes the form of a straight line with slope 0.96 m^3 NG/1 L gasoline and the relative performance of a natural gas conversion in a given driving mode is indicated by the vertical separation of the corresponding data point from this line. The data of this study (Figure 4) clearly display the extent of efficiency gain with the GMC and the extent of efficiency loss with the Ford van.

The most noteworthy observation with respect to emissions is that CO emissions of the GMC van dropped while those of the Ford van increased -- both rather sharply. As a result, under CNG use, CO emission levels of the converted GMC van are much lower than those of the Ford van. In contrast, the NO_x emission levels of the two converted vehicles under CNG use are much closer than those of the original vehicles under gasoline use. The performances of the two converted vehicles are also more comparable than those of the original vehicles.

The above observations indicate that the conversion of the two vehicles has resulted in relatively different operating conditions in the two vehicles. Specifically, the relative increase of CO emissions and performance and the relative decline in NO_x emissions in the Ford van indicate that the carburetion system in this vehicle is producing a fuel richer mixture.

4/ CONCLUSIONS

The limited number of fuel consumption, exhaust emissions and performance tests performed with the two Consumers' Gas vehicles that are in active fleet use indicate that:

1/ Vehicles (spark-ignition engines) running on CNG may achieve energy utilization efficiencies comparable to and higher than those achieved while running on gasoline.

2/ Use of CNG may result in a strong reduction of CO emissions.

3/ Vehicles using CNG may suffer a significant performance drop.

4/ CNG conversions carried out using the same conversion kit and conversion procedure may produce significantly different results in different vehicles. This observation suggests the need for careful optimization with individual engine/conversion kit combinations.

TABLE 1/ VEHICLE SPECIFICATIONS

	VEHICLE 1	VEHICLE 2
Type	Van	Van
Make	GMC	Ford
Model	Vandura 25	E-150
Model Year	1980	1980
Licence No.	AE8-857	AF6-523
Kilometrage	38789-40123	25239-26435
Gross Vehicle Weight	3000 kg	2815 kg
Engine Type	Gasoline; L-6	Gasoline; L-6
Engine Size	4.1 L	4.9 L
Transmission Type	A-3	A-3
Carburetor Type	2-BBL	2-BBL
Oxidation Catalyst	Yes	Yes
Air Injection	No	No
Exhaust Gas Recirc.	Yes	Yes
Evaporation Canister	Yes	Yes
Positive Crankcase Vent.	Yes	Yes

TABLE 2/ DYNAMOMETER PARAMETERS

	CMC Vandura 25	Ford E-150
Inertia Weight	4500 lb	4500 lb
Indicated Road Load*	13.5 HP	14.8 HP
Actual Road Load*	16.5 HP	17.5 HP
Tire Pressure	310 kPa	310 kPa
Cell Temperature	25°C	25°C
Cell Humidity	23.9 gr/lb	20.5 gr/lb
Cell Pressure	100 kPa	100 kPa

*At 80.00 km/h (50 mph)

TABLE 3/ VEHICLE DIAGNOSTICS*

With Natural Gas		GMC Vandura 25	Ford E-150
Curb Idle	(RPM)	740	680
Basic timing at Idle	(°BTDC)	17	23
Total Timing at 2500 RPM	(°BTDC)	53	54
Idle HC Emissions	(ppm)	0	20
Idle Co emissions	(%)	0.15	1.0
With Gasoline			
Curb Idle	(RPM)	750(650)**	820(700)**
Basic Timing at Idle	(°BTDC)	10(10)**	10(10)**
Total Timing at 2500 RPM	(°BTDC)	31	40
Idle HC Emissions	(ppm)	20	30
Idle CO Emissions	(%)	0.01	0.08

*Data in this table were obtained with garage equipment and should be considered qualitative only.

**Manufacturers' specifications

TABLE 4/ FUEL CONSUMPTION, EXHAUST EMISSIONS AND PERFORMANCE WITH GASOLINE

Fuel Consumption		GMC Vandura 25	Ford E-150
Urban Driving			
Cold-transient	(L/100 km)	17.94	18.33
Stabilized	(L/100 km)	17.45	16.99
Hot-transient	(L/100 km)	15.43	16.55
Combined	(L/100 km)	17.06	17.04
Highway Driving	(L/100 km)	12.50	13.13
Idling (Park)	(L/h)	2.19	2.44
Idling (Drive)	(L/h)	2.11	2.39
48.3 km/h Cruise	(L/100 km)	9.64	9.49
96.6 km/h Cruise	(L/100 km)	14.66	14.68

Hydrocarbon Emissions		GMC Vandura 25	Ford E-150
Urban Driving			
Cold-transient	(g/mile)	2.71	1.90
Stabilized	(g/mile)	0.868	1.58
Hot-transient	(g/mile)	1.020	1.61
Combined	(g/mile	1.29	1.65
Highway Driving	(g/mile)	0.302	0.72

CO Emissions		GMC Vandura 25	Ford E-150
Urban Driving			
Cold-transient	(g/mile)	17.81	34.25
Stabilized	(g/mile)	4.53	5.81
Hot-transient	(g/mile)	7.34	11.44
Combined	(g/mile)	8.04	13.24
Highway Driving	(g/mile)	3.52	3.81

TABLE 4/ (cont'd)

NO_x Emissions		GMC Vandura 25	Ford E-150
Urban Driving			
Cold-transient	(g/mile)	2.57	6.83
Stabilized	(g/mile)	1.35	4.19
Hot-transient	(g/mile)	2.04	7.21
Combined	(g/mile)	1.79	5.57
Highway Driving	(g/mile)	1.61	7.68

Performance	GMC Vandura 25	Ford E-150
0-96.6 km/h Acceleration Time		
In Drive (s)	14.0	17.6
In Second (s)	14.4	20.0
Power delivered at 80.0 km/h and WOT operation		
In Drive (kW)	75.0	64.0
In Second (kW)	75.0	60.3

TABLE 5/ FUEL CONSUMPTION, EXHAUST EMISSIONS AND PERFORMANCE WITH COMPRESSED NATURAL GAS

Fuel Consumption		GMC Vandura	Ford E-150
Urban Driving			
Cold-transient	(m^3/100 km)	15.20	19.07
Stabilized	(m^3/100 km)	15.79	17.19
Hot-transient	(m^3/100 km)	14.49	17.41
Combined	(m^3/100 km)	15.29	17.66
Highway Driving	(m^3/100 km)	11.76	14.49
Idling (Park)	(m^3/h)	2.30	2.33
Idling (Drive)	(m^3/h)	2.19	2.22
48.3 km/h Cruise	(m^3/100 km)	8.46	10.30
96.6 km/h Cruise	(m^3/100 km)	12.71	16.18
Hydrocarbon Emissions			
Urban Driving			
Cold-transient	(g/mile)	1.83	2.26
Stabilized	(g/mile)	1.36	1.91
Hot-transient	(g/mile)	1.55	1.86
Combined	(g/mile)	1.51	1.97
Highway Driving	(g/mile)	0.77	1.67
CO Emissions		GMC Vandura	Ford E-150
Urban driving			
Cold-transient	(g/mile)	0.58	68.70
Stabilized	(g/mile)	0.03	32.17
Hot-transient	(g/mile)	0.03	52.64
Combined	(g/mile)	0.16	45.28
Highway Driving	(g/mile)	0.03	46.21

TABLE 5/ (cont'd)

NO_x Emissions		GMC Vandura	Ford E-150
Urban Driving			
Cold-transient	(g/mile)	3.02	2.42
Stabilized	(g/mile)	0.99	2.44
Hot-transient	(g/mile)	1.85	3.01
Combined	(g/mile)	1.64	2.59
Highway Driving	(g/mile)	1.48	2.98

Performance	GMC Vandura	Ford E-150
0-96.6 km/h Acceleration Time		
In Drive (s)	24.1	23.2
In Second(s)	23.8	27.3
Power delivered at 80.0 km/h and WOT operation		
In Drive (kW)	47.7	44.4
In Second (kW)	45.6	44.4

TABLE 6/ ENERGY CONSUMPTION WITH GASOLINE AND NATURAL GAS

(Comparison of Energy Utilization Efficiencies)

GMC Vandura 25

		Gasoline	CNG	CNG* Advantage
Urban Driving	(MJ/100 km)	553	515	7%
Highway Driving	(MJ/100 km)	405	396	2%
Idling (in Drive)	(MJ/h)	68	74	-9%
Cruise (48.3 km/h)	(MJ/100 km)	313	285	9%
Cruise (96.6 km/h)	(MJ/100 km)	475	428	10%

FORD E-150

		Gasoline	CNG	Advantage
Urban Driving	(MJ/100 km)	552	594	-8%
Highway Driving	(MJ/100 km)	426	486	-14%
Idling (in Drive)	(MJ/h)	77	75	-3%
Cruise (48.3 km/h)	(MJ/100 km)	308	347	-13%
Cruise (96.6 km/h)	(MJ/100 km)	476	544	-14%

*Positive numbers indicate an energy utilization efficiency advantage for the CNG system.

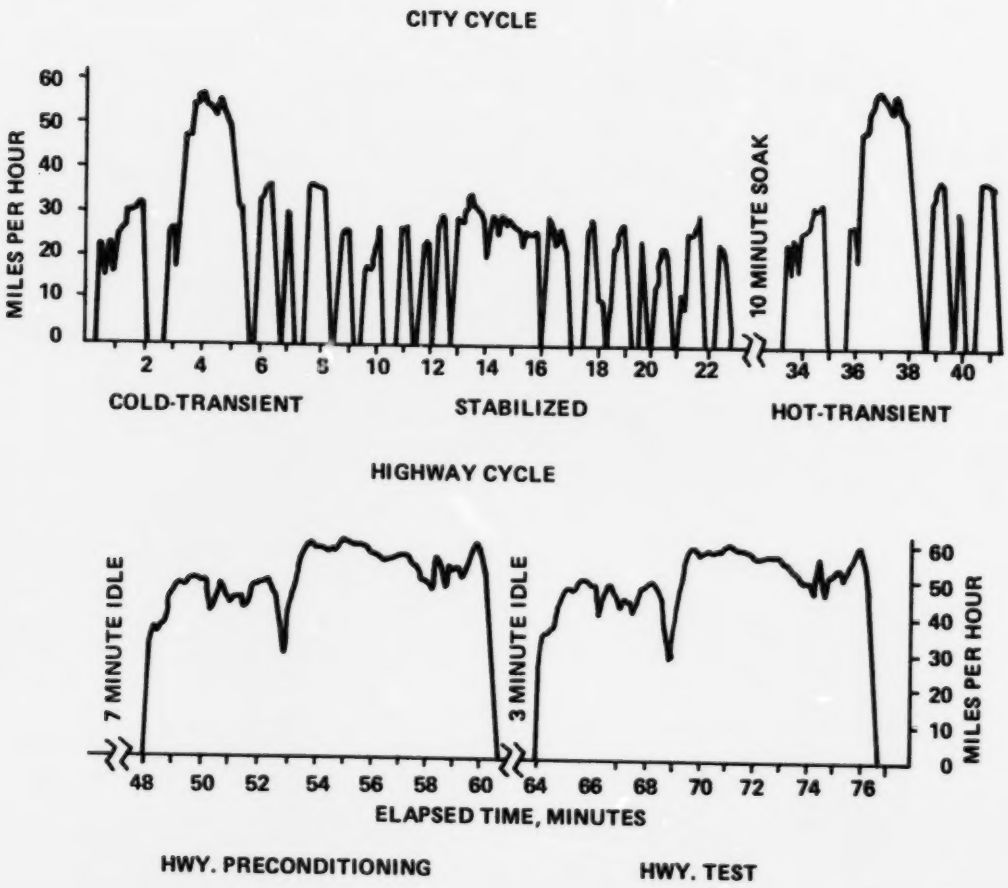

FIGURE 1/ CITY (URBAN) AND HIGHWAY DRIVING CYCLES

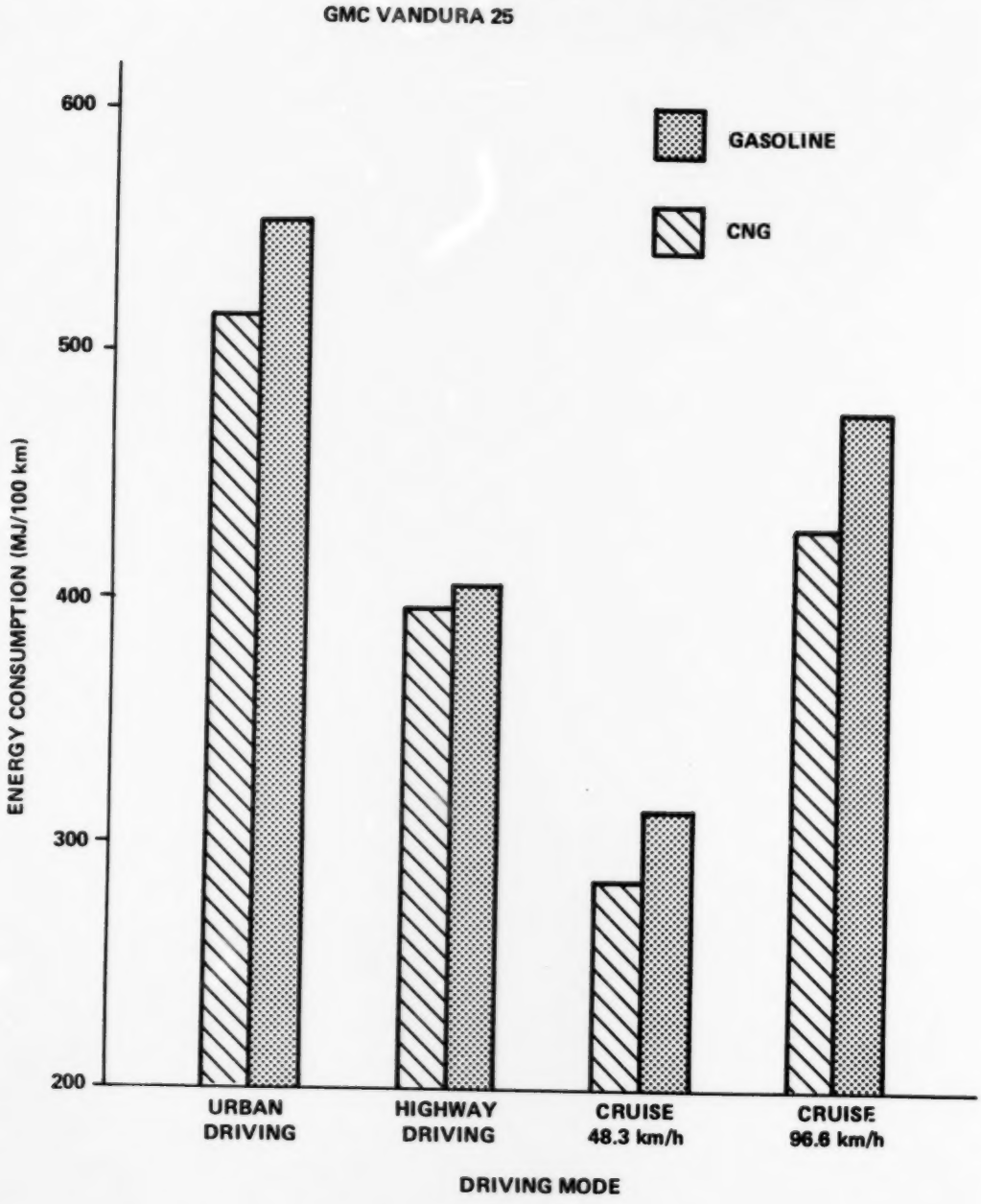

FIGURE 2/ ENERGY CONSUMPTION WITH GASOLINE AND NATURAL GAS
GMC VANDURA 25

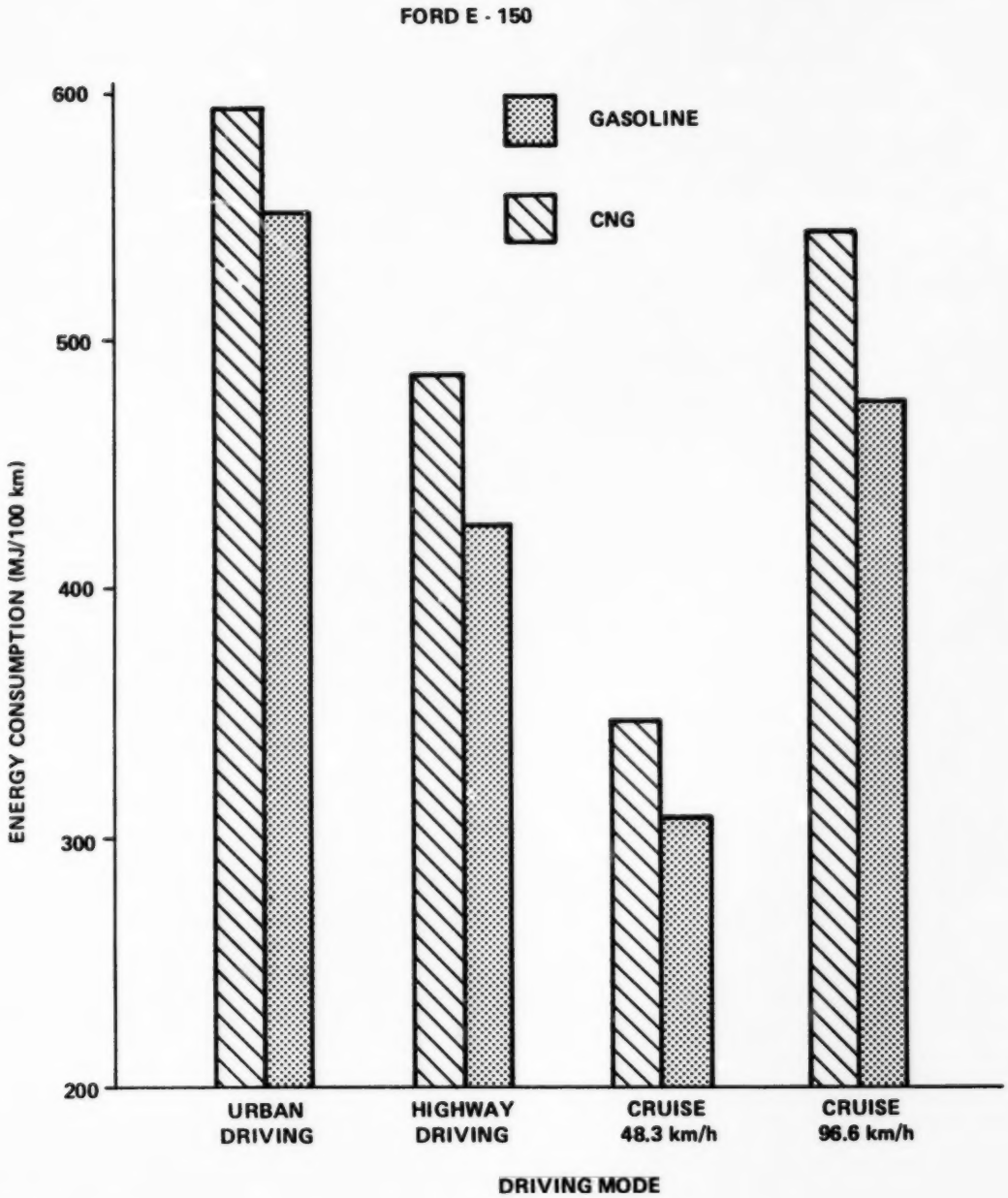

FIGURE 3/ ENERGY CONSUMPTION WITH GASOLINE AND NATURAL GAS
FORD E-150

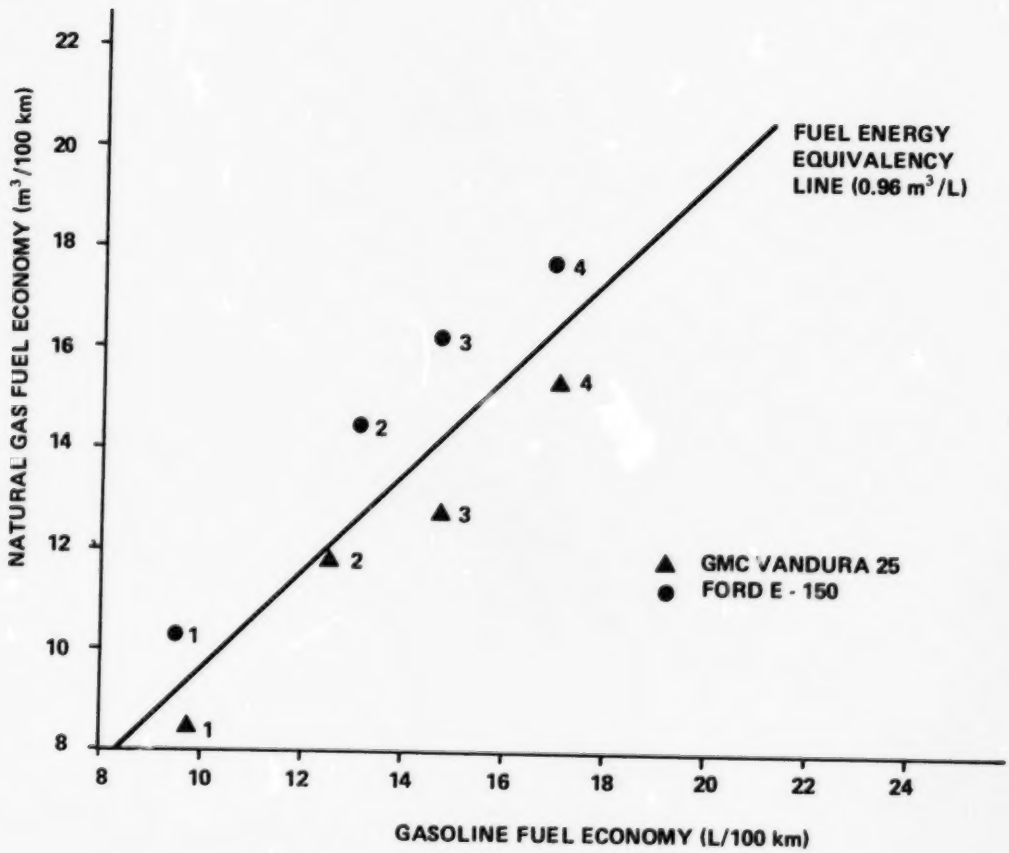
NATURAL GAS FUEL ECONOMY (m^3/100 km)
GASOLINE FUEL ECONOMY (L/100 km)
FUEL ENERGY EQUIVALENCY LINE (0.96 m^3/L)
GMC VANDURA 25
FORD E - 150
1 – URBAN DRIVING
2 – HIGHWAY DRIVING
3 – CRUISE (48.3 km/h)
4 – CRUISE (96.6 km/h)

FIGURE 4/ FUEL ECONOMY WITH GASOLINE AND NATURAL GAS